Systems Design Methodology to Develop Chrysanthemum Growing Systems

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Abstract

When chrysanthemum growers change soil for a soilless growing system they aim for labour cost reduction, quality and yield improvement and reduced emissions of nutrients. Because many attempts to come up with a viable soilless system failed, improvements and systemizations of the design process were examined. The design methodology chosen uses goal setting based on stakeholder engagement, systemised quantification of a set of conditions for the final system, and a systemised choice of competing systems and quantification of the properties of the competing systems. The set of conditions is assembled upon consultation of a wide variety of growers and experts in fields of plant protection, plant physiology, water management, substrate characteristics, economics and nutrition. The conditions and properties correspond to each other to the extent that both are based on the same measuring methods and expressed in the same units. Thus matches between conditions and properties can be scored. After the complete set of conditions and matching properties is scored, the average of the scores is taken as a measure for the suitability of the whole system. Because properties are quantified, the process is based on knowledge, and gaps in knowledge are identified. Favourable combinations of properties may be applied to systems lacking these properties in order to improve them. This design methodology was used to select and improve a set of 11 competing systems. The resulting 4 improved systems were built and used for growing in experiments. Systems included a soil bed, a sand bed, a peat bed and a cassette bed. The soil bed was a 70 cm deep bed of the original soil on a water impermeable foil with a drainage system. The sand bed was a 15 cm layer of coarse sand with a 5-10 cm under layer of coarse clay pellets including a drainage system which also supplied irrigation water i.e. sub irrigation. The peat bed was a 25 cm peat layer on a sub irrigation bench. The cassette bed was a 130×3×15 cm (length × width × height) container filled with peat. The cassettes were hung on a sub irrigation bench. Chrysanthemum press pot plants were planted on soil and sand beds and bare chrysanthemum cuttings were planted in the peat based systems. Chrysanthemums were grown for the first of 6 crop cycles. Results showed a 5-15% increase in dry matter production and 3-5 days shorter growing period in the peat beds and cassette beds. However, the economic performance is still marginally poor. Nevertheless, the systems tested are environmentally sound and comply with plant requirements for optimal growth. The sand bed and cassette bed may be further optimised by respectively EC control and top down irrigation.

INTRODUCTION

The European Union has set rules for the quality of surface waters in the EU Water Framework Directive (EU, 2000). The Dutch water boards plan to gradually change their existing system of regulations to meet the new European regulations (Van Staalduinen, 2009). The new regulations will insist on very low emissions of N and P from glasshouses by the year 2027.

Chrysanthemum growing in Holland represents with 500 ha the largest area of a single soil grown crop under glass (Alterra, 2008). Other major crops such as tomato, cucumber, sweet pepper and roses are principally (over 90%) grown on substrates with drain recirculation systems, thus greatly decreasing the emission of nutrients. In the past 30 years many attempts have been made to develop recirculating substrate systems for chrysanthemum to better meet environmental demands, and to open the way to automation to reduce labour costs. Publications on the various systems include sand beds (Wilson and Finlay, 1995) sub irrigation systems (Van Os, 1980; Buwalda et al., 1994; Warmenhoven and Baas, 1995) aeroponics (van der Hoeven and Zwinkels, 1991) and various gullies (Vermeulen, 2009). More recently the consortium Mobysant tried new approaches to mobile beds and gullies (Vermeulen, 2009; Pekkeriet and Sonneveld, 2007; Blok and Shao, 2008). Unfortunately, it became clear that the design process had serious flaws in the final systems for chrysanthemum (Blok and Shao, 2008), rose (Vegter, 2002; Sleegers, 2008) and gerbera systems (Arkesteijn, 2009). Irreparable flaws covered a wide range of topics including control of water and nutrient status, disease proneness and maintenance costs. Therefore a more systematic approach of system development was attempted.

An incomplete inventory of design systems identified two types of systems. In soil science, systems for creating soil use maps have been described (FAO, 1976). In technical engineering a History of use of Systems Engineering in Horticulture (van Henten et al., 2006) mentions various design processes, and applies Systems Engineering in a case study. These design systems aim to find viable technical systems in a systematic way as opposed to experimental implementation.

The chance to expand the existing Systems Engineering methodology for chrysanthemum growing systems arose when a new project on recirculation for chrysanthemum growers was initiated by the Dutch Water Boards.

METHODS AND MATERIALS

Methodology of System Design

For this study process steps were followed as shown in Figure 1. The steps were based on various sources (van Henten et al., 2006; Kroonenberg and Siers, 1999; FAO, 1976), but adapted in the course of the process. The idealized process starts with setting output-oriented goals. These are then specified into higher tier requirements. A description of the main functions of the desired new growing systems is used to generate alternative working principles. Combining choices from alternative working principles in a creative process resulted in a number of competing systems. The higher tier requirements are further differentiated into quantified lower tier conditions. The competing systems are reduced to quantified properties. The conditions and properties correspond to each other to the extent that the quantification of conditions and properties is based on the same measuring methods and expressed in the same units. Thus the matches between quantified conditions and properties can be scored. After the set of conditions and matching properties is scored, the average of the scores is taken as a measure for the suitability of the whole system. At this point the matching results can be used to find knowledge gaps and define new research challenges. The matching results can also be used to iteratively recombine advantageous properties into improved competing systems. Finally one or more new systems will be chosen.

Methodology of the Experiment

A soil bed and a sand bed system shared one Venlo type greenhouse compartment in the Bleiswijk experimental station, the Netherlands. The soil and sand beds were established in plots of 8.90×5.50 m, divided into six beds of 1.35 m wide with 30 cm paths. Each bed had its own drain pipe. The soil bed was a 70 cm deep bed of the original soil on a water impermeable foil, irrigated by overhead spraying of nutrient solution. The sand bed was a 15 cm layer of coarse 0.5-1.0 mm sand with a 5-10 cm under layer of coarse clay pellets, irrigated by sub irrigation through the drains but top irrigated in the initial stage. Both systems were planted with 14 day old rooted cuttings in press pots. The beds were treated as repetitions but it must be pointed out that this is not an independent repetition. Nevertheless an ANOVA analysis was performed. Planting and harvesting days may be found in Table 4.

A peat bed and a cassette bed system shared a second Venlo type greenhouse compartment. Peat beds and cassette beds were studied on respectively 11 and 2 independent sub irrigation tables. Each table had its own pump and recirculation tank. The peat bed was a 25 cm peat layer on a sub irrigation bench as typically used for container plants. The cassette bed was a 130×3×15 cm container filled with peat. The cassettes were hung in a sub irrigation bench similar to the one used for the peat bed. Bare, rootless chrysanthemum cuttings were stuck directly in both peat based systems. Data were analyzed using an ANOVA.

RESULTS

The Design Process

1. System Design Goals. The overall goals were set as non-soil based, emission free production systems for soil-based ornamental crops with a maximum added investment of 10% and perspectives of increased profitability for growers.

2. Higher Tier Requirements/Lower Tier Conditions. General conditions for profitable horticulture in a Dutch setting were split into lower tier conditions during workshops with horticultural professionals i.e. growers, breeders, advisors and technical suppliers.

3. Quantifying Conditions. In one-on-one interviews with research experts on plant physiology, crop protection, construction, rooting media, hydrology, emission, water management and economics, the lower tier conditions were quantified. The translation of research data to quantified guidelines for designing a new, at that point not defined system, seemed challenging to research experts. These challenges were further burdened by different opinions between experts on some matters. Explaining the impact and relevance of quantified conditions to the horticultural professionals required some discussion as well. Table 1a column 1 describes 24 selected quantified conditions. Table 1a column 2 gives the corresponding units. This implies agreement on a defined measuring method. Table 1a column 3 gives critical values for the quantified conditions, which implies knowledge permitted to pinpoint these critical values.

In discussions the cost argument often frustrated further consideration of novel system components. To focus this discussion, costs for each system were compared to standard soil growing. This resulted in one figure for the initial investment per area unit per year and one figure for the yearly instalment (Table 2). Furthermore the flower production of each crop cycle was evaluated against slowly increasing targets, with the final target delivering a feasible system.

4. Functions and Alternative Working Principles. In a growing system the main functions are providing a matrix for water and nutrient supply to the roots of the plant (Waisel et al., 1996), providing structural stability for the plant via its root system (Waisel et al., 1996) and providing the base for a logistical system of planting and harvesting. To create new growing systems within these three functions choices between alternative working principles were made:

Alternative Irrigation and Drainage Working Principles. These included sub irrigation, drip irrigation, overhead sprinkling, Nutrient Film Technique (NFT) and deep flow. For drainage steepness of slope, a drainage layer and active/passive drainage were considered.

Alternative Working Principles for the Matrix. The matrix influences water and nutrient supply and structural stability. Grains (soil, sand, clay grains, perlite, peat, coir), fibers (rockwool, coir fibre) and substrate-less systems (aeroponics, NFT) were considered.

Alternative Working Principles for the Logistic. Focus was on the shape and volume of the substrate, i.e. beds (2-dimensional, plants in a plane), gullies (1-dimensional, plants in a row) or containers (0-dimensional, single plants).

5. Competing Systems. Combining alternative working principles into a system is a creative process. Research experts would start with a basic principle of either one of the alternative working principles. The list of lower tier conditions would then help the researcher – often aided in workshop-setting by fellow researchers – to develop a complete concept that would comply with all aspects. This process led to 11 different system concepts of which only the 4 eventually selected systems are given:

Deep Soil Bed. Overhead irrigation, plastic foil at 50-70 cm, i.e. 30% slope, drainage pipes every 130 cm, soil substrate, 70 cm deep, plants in a plane.

Sand Bed. Sub irrigation, plastic foil at 20-25 cm i.e. 3% slope, drainage pipes every 130 cm, sand substrate 15 cm on 5-10 cm clay pellets, plants in a plane.

Peat Bed. Sub irrigation on a table, peat substrate 25 cm, plants in a plane.

Cassette Bed. Sub irrigation on a table, peat substrate 15×3 cm, plants in a row.

6. Quantification of System Properties. For each quantified condition a corresponding quantified system property was defined by the research experts. An example is root resistance (property 19), which may be expressed in kPa according to a standard method described by Blok in Raviv and Lieth (2008). Literature suggests a limit for unhampered growth at 400 kPa (Bullens, 2001). The final demand is therefore expressed as a resistance of <400 kPa (quantified condition). Table 1b column 5, 7, 9 and 11 give measurement values of the 24 selected system properties.

To assess which investment and which running costs could potentially be covered by an increase in profitability of the system, an estimate was made of the increase in profit by each system (Table 3). Profits usually arise from a combination of yield increase, costs reduction and labour savings. The yield assumptions were hotly debated and differed amongst researchers and horticultural professionals. However, the table helps to focus on components which make profit possible and reveals knowledge gaps.

7. Matching Conditions and Properties. Assessing the match of a system condition with a system property requires expertise and measurement data. The assessment may be qualitative or quantitative in terms of yield effect. Table 1b columns 6, 8, 10 and 12 give the scores for matches of the 24 conditions with the 24 measured system properties.

All individual scores for the matches are summated. In a quantitative match, with scores expressed as % yield increase or decrease, summated scores of total systems are directly comparable. In a qualitative match the individual matches may differ in effect upon plant growth. To adjust for this effect a weighing was introduced to increase or decrease the influence of a single match score on the summated score for a whole system. Table 1a column 4 gives weightings for the 24 selected system conditions.

An average of all the weighted scores of matches of conditions with properties is made. This system score is the key figure in the evaluation of individual systems. Table 1 shows the system scores under columns 6, 8, 10 and 12. A full evaluation of all four growing systems tested according to the system in Table 1 reveals that the soil bed has a relatively high score as has the cassette bed. Technically intermediate systems such as the sand bed and peat bed score lower values.

8. Selecting Systems. Based on the system score four out of the eleven systems were chosen for growth experiments. The soil bed was selected as the cheapest and most certain way to continue business without mayor adaptations. The peat bed and cassette bed were chosen because they offer a yield increase and give the perspective of future development towards mobile systems. Sand beds were selected as an intermediate.

9. Knowledge Gaps and R&D Challenges. After matching, all systems were revised to improve the low scoring qualities. Additional studies were performed for sub irrigation in a sand bed, active (e.g. suction driven) drainage, the effectiveness of steam sterilizing after a growth cycle, and capillary properties of some substrates.

10. Iterations and Technical R&D Challenges. Using the score lists in Table 1 the chosen systems were improved by selecting particularly advantageous alternative working principles. Technicians were asked for new or improved alternative working principles to cope with problems in otherwise attractive systems.

Results of the Experiment

All four chosen systems have been built on the test location of Wageningen UR Greenhouse Horticulture in Bleiswijk, The Netherlands (Figs. 2-5). The production results in Table 4 show that growth on the sand bed was initially >10% faster than on the soil bed but this advantage was in the end almost absent in terms of dry weight and reduced to 5-10% in terms of fresh weight. Soil analyses showed a high EC and pH for the sand bed (2.4 dS/m and 7.5 pH units). Leaves on the sand were too yellow until the ammonium supply was increased from 0.5 to 2.0 mmol/L. The mass production in the directly stuck treatments (peat bed and cassette bed) proved superior to the plantlets in the press pots (soil bed and sand bed) very quickly i.e. within 20 days even though the number of leaves remained lower to the end (data not shown). The fresh and dry mass production in the cassette beds were 10% higher than for peat beds (affirmed in later production cycles). No diseases were found. The peat bed system held up to 150 L of water per square meter after irrigation which is expected to be too wet for too long in the winter period. The sand bed showed no accumulation of organic matter in the deepest part of the sand, as the roots and press pots are removed after harvesting the stems. Accumulation of organic matter in sand beds was reported to become a source of *Pythium* problems (Anonymous, 1997). The roots in the soil bed were normal branching long roots. The sand bed roots were curly and did not penetrate the deepest saturated 1-3 cm of sand. The peat roots concentrated at the side panels whereas the roots in cassettes were spread very even throughout the material (Figs. 6-9).

DISCUSSION

No serious problems such as disease proneness, unequal distribution of nutrients and water or unsolvable logistics in planting, disinfection and harvest were evident in the study. Some questions remaining are the possible effects of water logging of the peat system in Dutch winter circumstances, the automation of harvesting roots and press pots in the sand bed system and the disinfection of water flows in an up scaled system.

In the design process both a creative and a disciplined phase seem essential for the outcome. The creativity is found in the brainstorming session for new systems. It benefits from a consideration of functions and alternative working principles even though the creative process will not and should not be confined to the possibilities listed. The quantification of conditions and properties is the most disciplined part of the process. It demands a lot of expertise in many fields. Indeed, additional research was necessary to find all system specific answers.

It is often uncertain just how much the actual properties will influence plant growth. The system is therefore quantitative in the description of properties and demands, but mostly qualitative when assessing the match between properties and demands. Assigning a weighting is one of the least transparent actions in the process. It reopened possibilities to favour systems and may have led to bias based on personal opinion rather than knowledge. Whenever possible scores should be quantitative to avoid weighting! This requires testing the growth response for a range of properties. The outcome of such tests will improve the general knowledge of plant cultivation.

The exact amount of profit potential of the new systems was hotly debated, but there was not enough knowledge to quantify effects and to predict whether effects would be additive. This design system will help identify opportunities for extra yield but does not substitute for experimentation on individual effects.

The yield results are largely as the design system predicted i.e. soil bed and sand bed yield equal, cassette beds proved the best and peat beds are intermediate. The sand bed systems scored less than soil, peat or cassette bed systems as the cost increase of the sand bed was not covered by a corresponding yield increase. The sand bed system is however believed to have more potential as the initial yield advantage was lost by inaccurate control of the nutrient solution on the roots, as witnessed by EC, pH and ammonium imbalances (De Kreij, 1995). This could mean that the advantage of controlling the nutrient solution in the sand bed may be larger than expected. Even so no system seems to be profitable yet. The most promising system is also the technically most advanced system (cassette bed), which requires large investments. The growers involved are not yet convinced of the economic perspective but there is willingness to pursue the sand bed system combined with direct sticking of transplants. The rooting in the sand bed shows that roots avoid the deepest part. This reduces root loss because of roots attached to the anti root fabric between sand and clay pellets. It also points to a relatively high water content in that layer. The roots in the cassettes shown no sign of stratification as previously expected. It is thought that the intense aeration through the anti root fabric lining the cassettes boosts root growth.

In conclusion the design process makes it possible to avoid specific weaknesses and identify the better systems while systematically taking twenty to thirty properties into account. This number of properties is too large to be considered by a single specialist but certainly not too difficult for a small group using a spreadsheet. The design system used also takes care of a proper description of the decision making process and asks for precise and growth related quantifications. This enables later researchers to further explore, change or improve quantified conditions as the economic situation changes or as knowledge evolves. The design system also offers possibilities for identifying particularly useful elements within a system. This offers a chance to take the better parts of a system and use them elsewhere. Having done so, the four systems tested will need to be further developed by long term testing and up scaling in practice.

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Tables

Table 1a. Matching specified system requirement to system properties.

No.	**Column 1** Requirement	**Column 2** Units	**Column 3** Critical value	**Column 4** Weight
1	Investment <10 Euro/m^2	Euro/m^2	10	10
2	Annual costs <2 Euro /m^2 (incl. more/less labour costs)	Euro/m^2	2	10
3	For mechanization: 3.20 wide, compaction <5% at 1.5 kg/cm^2	-	y/n	9
4	Durable: 10 year same shape + low risk for damaging	yr	10	9
5	Durability of hardware >10 year	yr	10	8
6	Possible on large scale (up to 10 ha)	-	y/n	5
7	Symmetrical drainage (vc in distance to the drainage point <20%)	% v.c.	20	5
8	Symmetrical supply of nutrients to root zone (as above <20%)	% v.c.	20	5
9	Buffering volume of substrate <15 L water/m^2	L/m^2	15	8
10	Maximum number of irrigation cycles per day >10	nr	10	4
11	The crop is moistened by overhead irrigation less than once a day	nr	1	8
12	Accumulation of salt in the top layer of the substrate <1 EC unit	dS/m	1.0	6
13	Water storage for recirculation/disinfection <10 L/m^2/d	L/m^2/d	10	4
14	Steam sterilizing <1 hour (also a measure for sufficient drainage)	hour	1	6
15	Energy for steam sterilizing or disinfection <1 m^3 gas/m^2	m^3/m^2	1	4
16	Steam resistant materials. Stable for >1 hour at 105°C	hour	1	7
17	Air volume >5% in every position in the substrate	%-v/v	10	10
18	Height of substrate is 20-40% of the pF 1/3 max. water content	%	20-40%	2
19	Root resistance <400 kPa	kPa	400	3
20	Root hold in the system to prevent stem bends	-	y/n	1
21	No chemical changes in substrate upon use and reuse	-	y/n	4
22	No physical changes upon use and reuse (BD, AFP, OM).	-	y/n	9
23	Drainage after an irrigation cycle stops <30 min	minute	30	5
24	Capturing all water streams 100% (no emission)	%-v/v	99	10

Table 1b. Matching specified system requirement to system properties for 4 systems.

No.	**Column 2**	**Column 5**	**Column 6**	**Column 7**	**Column 8**	**Column 9**	**Column 10**	**Column 11**	**Column 12**
	Units	Soil bed	Score	Sand bed	Score	Peat bed	Score	Cassette bed	Score
1	Euro/m^2	€ 13.64	7	€ 19.21	4	€ 22.96	3	€ 26.68	2
2	Euro/m^2	€ 1.91	6	€ 2.62	4	€ 5.18	2	€ 7.59	2
3	-	Yes	8	Probably	6	Adapt	6	Adapt	6
4	yr	10 yr	8	8-12 yr	5	3 yr	4	10-15 yr	6
5	yr	10 yr	8	10-12 yr	6	10 yr	6	10-15 yr	6
6	-	Possibly	4	yes	6	yes	6	yes	6
7	% v.c.	< 5%	9	< 5%	9	< 5%	9	< 1%	10
8	% v.c.	10%	6	< 5%	9	< 5%	9	50%	2
9	L/m^2	> 500 L/m^2	5	75 L/m^2	5	110 L/m^2	5	5 L/m^2	10
10	nr	<1	3	1	4	1	4	10	10
11	nr	1	6	1	6	1	6	0	6
12	dS/m	0.5 dS/m	5	0.5 dS/m	4	0.5 dS/m	4	0.5 dS/m	6
13	L/m^2/d	1 L/m^2/d	8	1 L/m^2/d	8	5 L/m^2/d	6	5 L/m^2/d	6
14	hour	2 h	4	0.5 h	8	1.5 h	4	none	10
15	m^3/m^2	3 m^3/m^2	4	0.5 m^3/m^2	8	1.5 m^3/m^2	4	none	10
16	hour	> 5 h	7	> 5 h	6	> 5 h	6	> 5 h	6
17	%-v/v	10%	7	10%	7	5%	6	15-20%	8
18	%	20%	5	45%	5	50%	4	30%	6
19	kPa	500	2	500	2	200	8	200	8
20	-	Yes	6	Yes	6	Yes	6	Yes	6
21	-	Yes	4	Yes	6	pH	4	Yes	8
22	-	AFP, OM	4	OM	4	AFP, BD	4	none	8
23	minute	30 min	7	10 min	8	30 min	7	5 min	9
24	%-v/v	100%	6	100%	8	100%	8	100%	6
			6.1		**5.9**		**5.3**		**6.5**

Table 2. Cost estimate for systems, transport tables, labour and dpm.

	Units	Reference	Deep soil bed	Sand bed	Peat beds	Cassettes
Rooting	Number of days	14	14	14	10	10
	Plant density	400	400	400	53	212
Long day period	Number of days	14	14	12	8	8
	Plant density	51	51	51	53	106
Short day period	Number of days	51	51	51	51	51
	Plant density	51	51	51	53	53
Cultivation length	Days	79	79	77	69	69
Space requirement	daym^2/plant	1.31	1.31	1.27	1.30	1.08
Loss	%	3.75	3.75	3.75	3.75	3.75
Production	plant/m^2/y	268	268	277	270	324
Share of the rooting compartment	%	2.7	2.7	2.8	14.5	4.3
Production ex rooting	plant/m^2/y	276	276	284	316	339
Dpm-costs	€/m^2/year	20.10	21.52	22.78	36.94	37.59
Energy costs ex steam sterilizing	€/m^2/year	8.00	8.00	8.00	8.00	8.00
Energy steam sterilizing	€/m^2/year	0.80	0.80	0.40	0.08	0.04
Total fixed costs	€/m^2/year	28.90	30.32	31.18	45.02	45.63
Total fixed costs	€/plant	0.104	0.109	0.109	0.161	0.136
Labour costs	€/plant	0.045	0.045	0.045	0.036	0.031
Plant costs (ex-propagation)	€/plant	0.050	0.050	0.050	0.045	0.045
Nutrients and crop protection	€/plant	0.008	0.008	0.008	0.008	0.008
Packaging and transport	€/plant	0.020	0.020	0.020	0.020	0.020
Total variable costs	€/plant	0.123	0.123	0.123	0.109	0.104
Total costs per plant	€/plant	0.227	0.232	0.231	0.270	0.240
Extra investment space			€ 9.11-	€ 8.69-	€ 77.69-	€ 28.34-

Table 3. Potential for profit.

	Euro	Calculation
Price	0.23	
Yield per square meter	63.25	
Cost of bare cuttings	0.045	
Cost of press pots	0.0075	
Cost per rooted cutting	55	
Number of cultivation cycles a year	5	
Number of plants per square meter per year	275	Nr of cycles x number of plants per m^2
Costs of propagated cuttings per square meter per year	14.44	Nr of plants per m^2 × costs of plant and pot
Yield advantage by steam sterilizing	0.50	
Yield effect of control of the room temperature	0.10	Pm
Yield increase by more frequent refreshment of the nutrients around the roots	1.00	Pm
Yield increase by suction controlled replacement of nutrient solution	0.50	Pm
Area efficiency increase by using the paths 10 cm on 130 cm	4.87	Yield × 10/130
Area efficiency by using multiple propagation layers	1.20	Pm
Direct sticking bare cuttings; increase in growth speed 1.5 days x 4 cycles	1.22	Yield × 1/52
Direct sticking bare cuttings; cost advantage over rooted plants	2.06	Costs per press pot × number/m^2/yr
Increased flower quality by avoiding overhead irrigation in the last weeks	0.50	Pm
Increased crop quality and growth by heating under the crop (air circ.)	0.50	Pm
Labor advantage for central harvesting	0.50	Pm
	12.94	

Table 4. Starting dates and fresh and dry weight yields plus the resulting dry matter percentage on respectively 27-7-2009, 28-8-2009 and the final harvest on 18-9-2009. Statistics on fresh weight 18-09-2009.

Treatment	Start date	Fresh weight (g)			Dry weight (g)			Dry matter (%, g/g)		
Soil bed*	14-07-2009	11.3	83.3	117 a	1.3	9.5	14.4	11.9	11.5	12.3
Sand bed*	14-07-2009	13.1	89.8	128 a	1.6	10.4	14.9	11.9	11.6	11.6
Peat bed	09-07-2009	19.5	107.4	152 b	1.8	10.4	16.4	9.3	9.7	10.8
Cassette bed**	09-07-2009	16.5	107.4	174 c	1.7	11.1	20.8	10.0	10.4	12.0

*Peat bed and cassette bed crops grew from direct stuck cuttings in a separate compartment.

**The production on 18-9-2009 may be flattered by extra light as guard plants were harvested at 28-08-2009.

a, b, c Statistical significance at the 5% level, LSD is 21.9. Data without shared letters are significantly different.

Figures

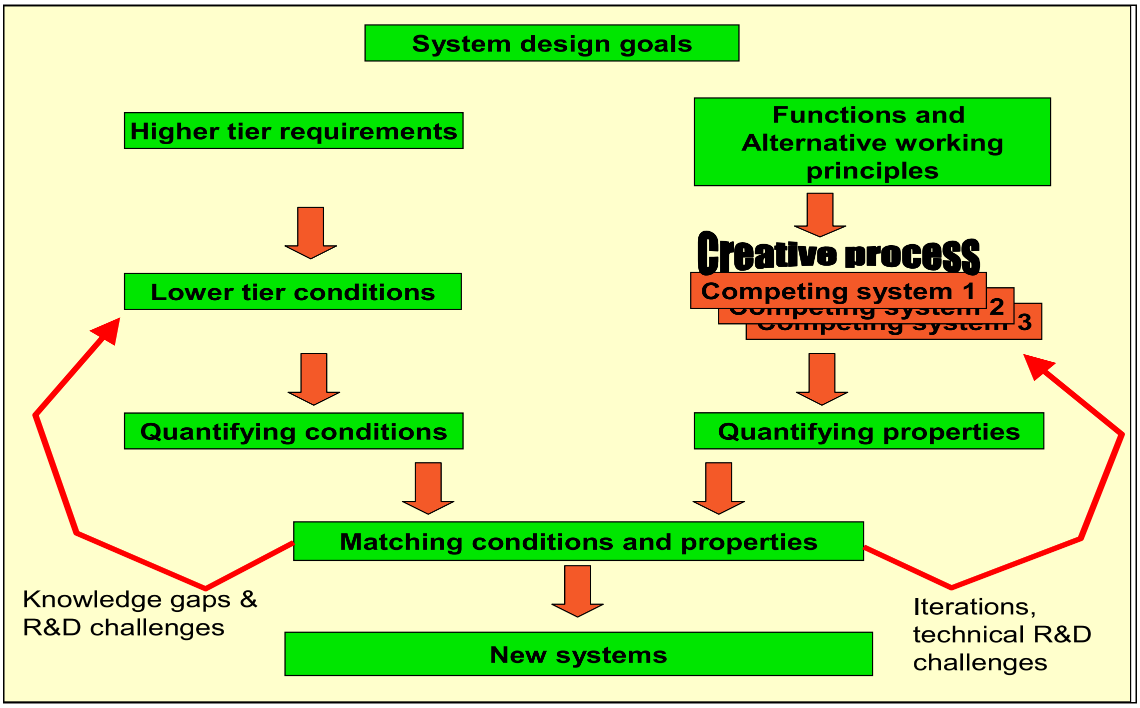

Fig. 1. Schedule of the systems design process.

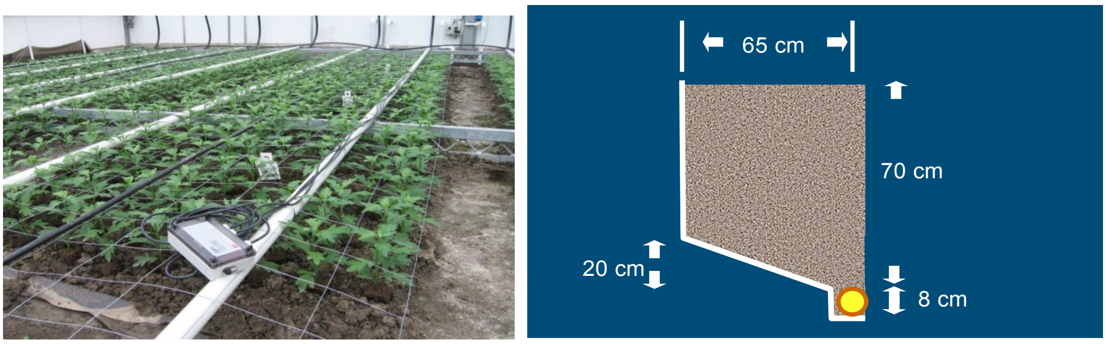

Fig. 2. Deep soil bed. Inlay: schematic presentation of 70 cm dug out soil with steep slope for drainage. Irrigation with sprinkler irrigation.

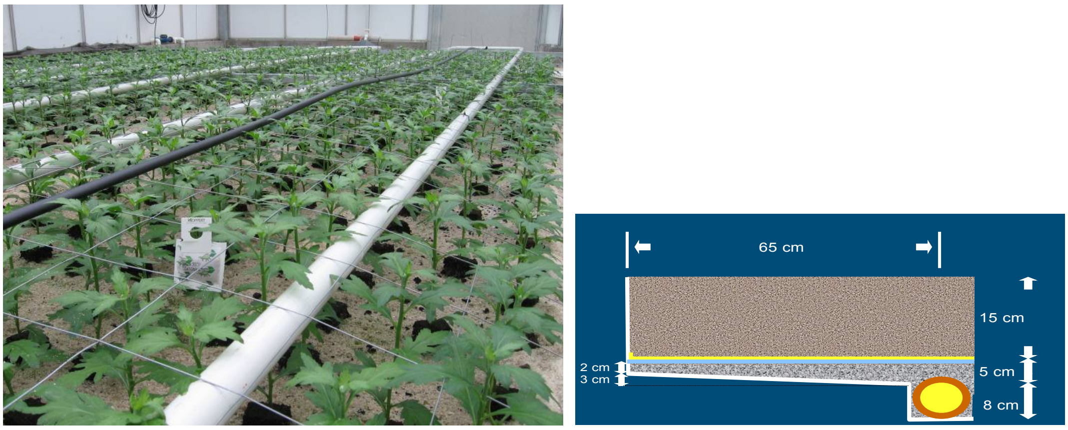

Fig. 3. Sand bed. Inlay: schematic presentation of 15 cm high sand bed on an anti-rooting layer, followed by a water distribution layer and a layer of clay grains. Irrigation is done with sprinkling and ebb-flow, according to needs and plant development.

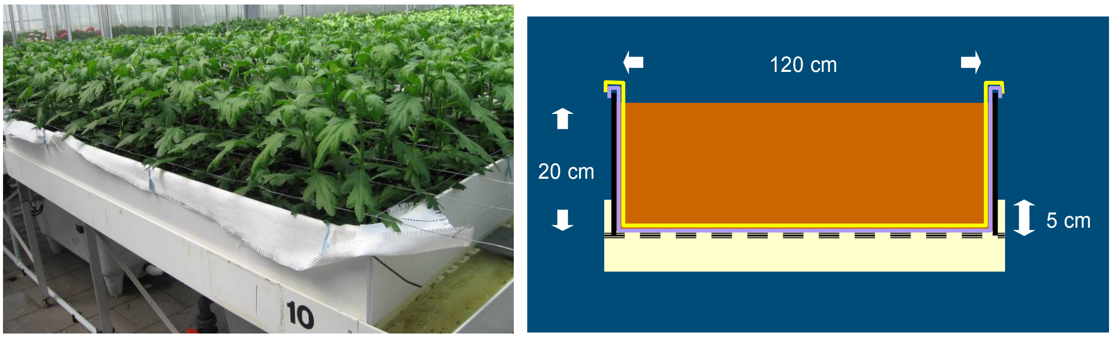

Fig. 4. Peat bed. Inlay 15 cm high peat bed on ebb-flow irrigation.

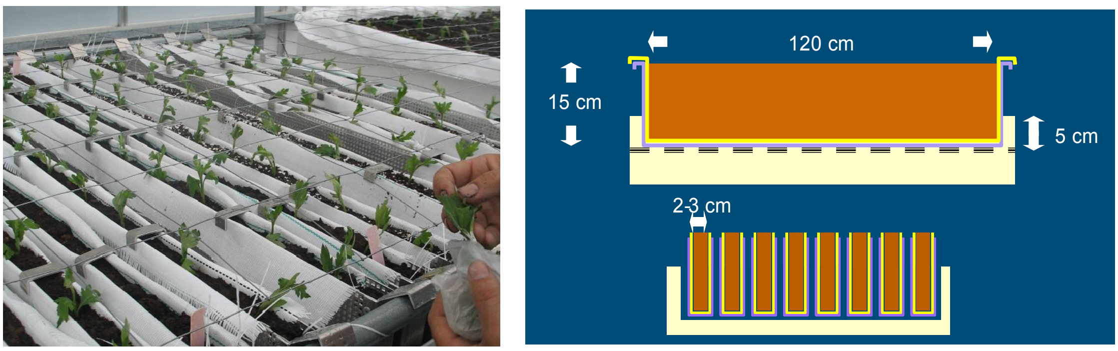

Fig. 5. Cassette system with direct sticking of chrysanthemum plantlets. Inlay: 3 cm-wide layers of substrate of 15 cm high on ebb-flow irrigation.

Fig. 6. Roots in the soil bed.

Fig. 7. Roots in the sand bed.

Fig. 8. Roots in a peat bed variant.

Fig. 9. Roots in the cassette bed.